<u>MEMORANDUM</u>:

DATE: 4 September 1998

SUBJECT: CTWG Gas-Fired Combustion Turbine MACT Considerations

FROM: Combustion Turbine Work Group

TO: ICCR Coordinating Committee

The Combustion Turbine Work Group (CTWG) formed a task group to develop a white paper on issues for EPA to consider in developing MACT for gas-fired combustion turbines. The task group was comprised of one EPA representative and members of the turbine manufacturing and user community. The attached document is the white paper developed by this task group.

The CTWG concurs that this information may be valuable to EPA in developing regulations for combustion turbines and requests that the ICCR Coordinating Committee pass it to EPA as a Work in Progress Item.

Attachment: **Gas-Fired Combustion Turbine MACT Considerations**

Gas-Fired Combustion Turbine MACT Considerations

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List of Attachments

The reference for Section 9 “Health Risk Analysis of the ICCR Combustion Turbine Emissions Database” (a separate CTWG report to Sims Roy of EPA from Greg Adams of the L.A. County Sanitation Districts) is available by contacting Mr. Sims Roy of EPA. The report has not been reviewed by EPA.

Gas-Fired Combustion Turbine MACT Considerations

1. Background and Development

This "considerations" paper had its origin in February 1998 at the Coordinating Committee meeting in Winston-Salem, North Carolina when several members accepted EPA's challenge to think outside the box innovatively with ways to come up with a timely final work product. A number of CTWG members were informally discussing testing of turbines for very specific information to discern subtleties in lean pre-mix combustors versus diffusion flames when it became apparent that such polishing and refinement was probably leaps and bounds ahead of where other ICCR workgroups were. The subgroup recognized that this status was largely because natural gas was the fuel of choice for the industry and formed the bulk of the emissions test data in EPA's possession. In balance, the CTWG believed that "gas" was environmentally friendlier when compared with many of the fuels and wastes that were being considered by the other workgroups. In fact, the CTWG was aware that several states advocated gas as part of their clean fuels programs and that several program studies within EPA were leaning toward the favorable characteristics of natural gas if one had a choice of burning a fossil fuel. The CTWG discussed the pros and cons of delisting gas-fired combustion turbines entirely as well as requesting EPA through the Coordinating Committee to place the category in a low-priority status. These approaches were abandoned for one reason or another. The large majority of the CTWG agreed that a "preponderance of evidence" argument might be assembled to both convince EPA to make a determination that gas-fired combustion turbines should not be of primary focus in the ICCR process and that hopefully a formal determination along these lines would avoid the Section 112(j) case-by-case hammer provisions.

At the last CTWG meeting in Chicago on August 26-27, 1998, however, the draft paper was revised in view of the completion of the paper documenting the poor cost effectiveness of add-on controls and the group's desire to more formally address pollution prevention issues raised by that ICCR subgroup (the CTWG had addressed P2 earlier within the "Rationale for Development of MACT Floor for Existing Combustion Turbines" that was presented to and forwarded by the Coordinating Committee to EPA as a consensus document on April 28, 1998 at Fort Collins, Colorado). The CTWG in Chicago agreed to change the focus of the gas paper, to make it a non-closure item, to extract the P2 sections into a separate paper and simply cross-reference them, and in general, to present considerations by the CTWG to the Coordinating Committee so that EPA can take them into account in their deliberations in the future over MACT standards for new and existing gas-fired stationary combustion turbines.

2. Gas Fired Combustion Turbine MACT Considerations

The CTWG requests that the Coordinating Committee forward to EPA the following considerations for EPA use in their deliberations for a gas fired combustion turbine MACT:

- The Combustion Turbine Work Group (CTWG) had previously concluded, and the Coordinating Committee agreed that, using all available information in the ICCR databases, there is no identifiable subcategory or relationship representing a best performing 12 percent of combustion turbines and, hence, there was no MACT floor for existing combustion turbines. This was largely based on an analysis of 42 test reports for natural gas.

- Natural gas and refinery gas for all practical emissions purposes have comparable low HAPs emissions.

- The federal government and several states (California in particular) explicitly hold natural gas to be a "clean fuel." The Clean Air Amendments of 1990 and the Energy Policy Act of 1992 (EPAct) establish requirements for the use of clean fuels. In extreme non-attainment areas, utility and industrial boilers emitting 25 TPY or more of NOx are required to use clean fuels more than 90 percent of the time except during an emergency (Section 182(e)(3)). In the South Coast AQMD, natural gas is the standard against which comparable clean fuels are judged per the SCAQMD BACT Guidelines.

- The Utility Air Toxics Report to Congress essentially says that there is no toxics threat from natural gas fired utility boilers burning quantities of natural gas vastly larger than the largest combustion turbine.

- Combustion turbine combined cycle and cogeneration systems are among the most efficient energy conversion devices on the market today which, when coupled with extremely low carbon monoxide LAER requirements, should assure low HAP emissions in this growing sector of energy conversion devices and make them suitable for siting even in urban areas.

- No operator influenced good combustion practices that directly relate to hazardous air pollutants (HAPs) formation in combustion turbines have been identified by the CTWG since such features are built in by the turbine manufacturer and cannot be manipulated by the operator.

- The CTWG believes that pollution prevention is intrinsically occurring by the deployment and operation of natural gas fired turbines. A detailed pollution prevention paper has been prepared by the CTWG and submitted as a work in progress item along with this paper.

- While it is not demonstrably clear from the EPA emissions database that any emission control would be effective in removing organic HAPS from the exhaust of combustion turbines, an economic analysis performed by the CTWG of adding an oxidizing catalyst to control organic HAPs resulted in an extremely high cost effectiveness indicating that it would not be economically viable to use such controls for HAPs.

- The CTWG studied the draft Section 112(f) residual risk proposal to verify where combustion turbines would fall in that analysis. A conservative screening risk assessment performed by the CTWG fell below the draft Section 112(f) benzene guidance for every compound from every turbine contained in EPA's emissions database.

The following sections support or elaborate on the considerations listed above:

3. Combustion Turbine Gas Fuel and Natural Gas Fuel Equivalency Definition

Combustion turbines that burn gaseous fuels like natural gas and other gases with equivalent emissions characteristics produce very low levels of organic HAPs compounds. This section addresses characteristics of gases that are equivalent to natural gas from the standpoint of HAPs emissions.

For purposes of discussion in this section, fuel gases that are equivalent to natural gas in formation of organic HAPs during combustion are defined as: (1) A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases found in geologic formations beneath the earth's surface, of which the principal constituent is methane; (2) Liquid petroleum gas, as defined by the American Society of Testing and Materials in ASTM D1835-82, Standard Specification for Liquid Petroleum gases; (3) Gaseous fuel derived from crude oil or petroleum that has similar HAPs emissions characteristics to natural gas; (4) synthetic gases derived from coal and other organic material. The EPA draft definition of solid waste also defines natural gas as (1) and (2) above.

Attachment A contains a more thorough analysis of the rationale supporting the equivalency of gas fuels and natural gas using available EPA emissions databases.

4. Estimate Of Annual HAP Emissions From Gas Turbines

For "benchmarking" comparative purposes, the CTWG estimated the total annual US emissions of organic HAPs from natural gas-fired combustion turbines. The emissions from individual combustion turbines of various sizes were estimated using assumptions as follows:

a. Use the EPA inventory database to identify average capacity turbine and average hours/year utilized.
   Average Turbine size - 30 MW — Assume Average Turbine Efficiency - 30%
   Average Utilization - 5000 hrs/yr — Assume High Load condition- 85 to 100% load

b. Estimated number of turbines in US - 8000

c. Emission Factors – The CTWG used emission factors derived from the EPA emissions database for natural gas - for all pollutants. The CTWG did not use any test reports that did not have complete information and did not use test results where turbines were operating at less than 80% load. Emission tests that had all non-detects measurements were not used. For emission tests that had at least one measurement above the detection limit, the detected measurement was used and the non-detected measurements were assumed to be at the detection limit. Attachment B summarizes the results.

- Calculation of Estimated Annual HAP Emissions from all turbines in US:

$$\text{Total Natural Gas used per year} = \frac{30\text{MW x }5000\text{hrs x }8000\text{ turbines}}{.30\text{ x }.293\text{MW/MMBTUH}} = 1.36 \times 10^{10}\text{ MMBTU/YR}$$

Pollutant	Emission Factor (lb/MMBtu)	**Emissions (Ton/yr)**
Acetaldehyde	9.12×10^{-5}	620
Acrolein	5.49×10^{-6}	36
Benzene	1.03×10^{-5}	70
Ethylbenzene	4.1×10^{-5}	282
Formaldehyde	7.13×10^{-4}	4867
Naphthalene	1.46×10^{-6}	10
PAH's	2.23×10^{-6}	15
Toluene	1.42×10^{-4}	970
Xylene	4.59×10^{-5}	318
TOTAL HAPs		**7188**

This total estimated annual organic HAPs emission mass from combustion turbines cannot be compared with the other combustion device categories being studied under he ICCR since many more data gaps exist and many assumptions, possibly guesses, would have to be made. The above figure is simply a "benchmark" reference to compare combustion turbines with other sources of toxic air pollution around the United States. For example, the 1996 Toxic Release Inventory (TRI), the latest available on the EPA website, indicates that on-site point source discharges to the air were approximately 550,000 tons per year. Also, in the February 1998 EPA report entitled "Taking Toxics Out of the Air" that describes the progress in setting MACT standards, EPA estimates that mobile sources comprise 41% of the U.S. toxic inventory, with area sources and major stationary sources comprising the balance at 35% and 24%, respectively.

Calculation of Estimated Emissions
From a 200MW, 50 MW and 10MW Turbine Operating 8000 hrs/yr Using Natural Gas Fuel

- Assumptions: The CTWG looked even more conservatively at several turbine model sizes and assumed, in the worst case, that a turbine would be operating 8000 hours per year:

Total Fuel Consumed =

200MW - $1.82\text{x}10^{7}$ MMBtu/yr $\rightarrow$ $\frac{200\text{MW}}{.3} \text{ x } \frac{8000 \text{ HR}}{\text{YEAR}} \text{ x } \frac{\text{MMBTUH}}{.293\text{MW}}$

50MW - $4.5\text{x}10^{6}$ MMBtu/yr $\rightarrow$ $\frac{50\text{MW}}{.3} \text{ x } \frac{8000 \text{ HR}}{\text{YEAR}} \text{ x } \frac{\text{MMBTUH}}{.293\text{MW}}$

10MW - $1.82\text{x}10^{6}$ MMBtu/yr $\rightarrow$ $\frac{10\text{MW}}{.3} \text{ x } \frac{8000 \text{ HR}}{\text{YEAR}} \text{ x } \frac{\text{MMBTUH}}{.293\text{MW}}$

Pollutant	Emission Factor (lb/MMBtu)	Emissions (Ton/yr) 200MW	50MW	10M
Acetaldehyde	$9.12\text{x}10^{-5}$	0.83	0.21	0.04
Acrolein	$5.49\text{x}10^{-5}$	0.05	0.01	0.00
Benzene	$1.03\text{x}10^{-5}$	0.09	0.03	0.01
Ethylbenzene	$4.1\text{x}10^{-5}$	0.40	0.09	0.02
Formaldehyde	$7.13\text{x}10^{-4}$	6.5	1.6	0.33
Naphthalene	$1.46\text{x}10^{-6}$	0.01	0.32	0.00
PAH's	$2.23\text{x}10^{-6}$	0.02	0.00	0.00
Toluene	$1.42\text{x}10^{-4}$	1.3	0.32	0.07
Xylene	$4.59\text{x}10^{-5}$	0.42	0.1	0.02
TOTAL HAPs		**9.62**	**2.68**	**0.49**

The CTWG wishes to note that even the emissions from the largest, currently commercially available combustion turbine manufactured in the United States would not exceed the 10 ton per year major source threshold for organic HAPs, on an individual or collective basis.

5. Regulatory and Policy Precedents

EPA has recognized the environmental benefits that can be obtained by encouraging increased use of cleaner-burning gas. For example, in the proposed new source performance standards (NSPS) for industrial and commercial boilers (62 FR 36948), EPA adopted a fuel-neutral standard that would allow gas technologies to compete with other fossil fuels on a level playing field. EPA recognized this would help improve air quality because it would help remove disincentives for using "clean fuels (i.e. natural gas)." In particular, on page 36953 EPA states that "the clean fuel approach fits well with pollution prevention which is one of the EPA's highest priorities" as well as "air toxic compound emissions can be dramatically reduced, depending on the degree of natural gas use."

The President has issued a directive that states "The Administration recognizes the environmental, economic, and national security benefits of encouraging the use of natural gas." It further states "President Clinton is directing EPA to encourage the use of natural gas as a pollution control strategy under the Clean Air Act." The directive incorporates the development of technologies that could contribute to significant reductions in emissions and specifically includes "advanced natural gas turbine and fuel cell technologies" (this information can be found on the Energy Information Administration web page).

As further evidence that EPA is encouraging the use of combustion turbines, it should be noted that EPA includes the installation of combustion turbines at compressor stations as a Best Management Practice under the natural gas STAR Program because they are more efficient at natural gas combustion.

EPA, in its February 6, 1998 Oil and Natural Gas Production and Natural Gas Transmission and Storage MACT proposed rulemaking (63 Fed. Reg. 6304), chose to regulate only specific types of equipment within these industries. Although these industries have a number of different although often low level HAP emissions sources, only storage tanks, glycol dehydrators and gas plant fugitives have regulatory requirements under this proposal. EPA also included applicability cutoffs for dehydration units based on 3 million standard cubic feet per day of gas throughput and one ton per year of benzene emissions. The MACT floor for units below these thresholds was no control.

The federal government and several states (California in particular) explicitly hold natural gas to be a "clean fuel." The Clean Air Amendments of 1990 and the Energy Policy Act of 1992 (EPAct) establish requirements for the use of clean fuels. In extreme non-attainment areas, utility and industrial boilers emitting 25 TPY or more of NOx are required to use clean fuels more than 90 percent of the time except during an emergency (Section 182(e)(3)). In the South Coast AQMD, natural gas is the standard against which comparable clean fuels are judged per the SCAQMD BACT Guidelines.

6. Utility Air Toxics Study Favors Natural Gas Combustion

EPA has already provided ample justification for focusing its main energies on other than gas-fired combustion turbines in the MACT standard-setting process. EPA recently concluded a study for Congress of HAPs emissions from electric utility steam generating units, which was required by the Clean Air Act Amendments of 1990. In this study, EPA considered the emissions of HAPs from all electric utility steam generating units. This population of units includes units fueled by natural gas, fuel oil, and coal.

In the Utility Air Toxics Report to Congress, EPA concludes that emissions of HAPs from gas-fired electric utilities are of no significant public health concern. In the Executive Summary, EPA states that, "The impacts due to HAP emissions from gas-fired utilities are negligible based on the results of this study; therefore, the EPA feels that there is no need for further evaluation of the risks of HAP emissions from natural gas-fired utilities." (*Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units – Final*

Report to Congress, U.S. EPA Air Quality Planning & Standards Division, EPA Document #EPA-453/R-98-004a, February 1998, p. ES-27.) In fact, EPA goes a step further in the report proper, by suggesting that burning natural gas in electric utility units instead of coal or oil would be an effective alternative HAP control strategy. Specifically, the EPA report states in Section 14.6 (page 14.6), Alternative Control Strategies, that "Conversion of coal- and oil-fired units to natural gas firing *effectively eliminates emissions of HAPs*" (emphasis added).

While steam electric units and combustion turbines generate electricity by different physical processes, the underlying fuel combustion process is essentially identical. Any characterization of HAP emissions from steam electric units is equally applicable to combustion turbine units. Therefore, the conclusions drawn by EPA regarding emissions of HAPs from gas-fired steam electric units are also valid for gas-fired combustion turbine sources as a category.

In addition, relative contributions of HAPs from combustion turbine sources and steam-electric utility units should be considered. The largest gas-fired utility steam units in the United States are rated at approximately 900 megawatts (MW), and consume about 9,000 million Btu per hour (MMBtu/hr) of natural gas. By comparison, the largest combustion turbines in the United States are significantly smaller and have much better overall heat rates. Less fuel use per megawatt of output and smaller size mean that emissions of HAPs from gas-fired combustion turbine sources are less than that from gas-fired utility steam-electric sources. If emissions of HAPs from gas-fired utility units are of no concern, then the much lower emissions of HAPs from combustion turbines should also be of no concern. The excellent fuel economy demonstrated by newer combustion turbine systems will also go a long way to reduce global warming impacts.

7. Section 112(f) Draft Residual Risk Report to Congress

The draft Section 112(f) Residual Risk Report to Congress utilizes the procedure established in the 1989 benzene NESHAP as the basis of human health risk management decision-making for the residual risk program. At page ES-7 of the draft, "Congress said in the 1990 CAA Amendments that risk management under the residual risk program should conform with the risk management approach in the pre-1990 version of the CAA, and specifically referred to the 1989 benzene NESHAP." EPA plans to employ a two tier risk assessment process using, first, a screening level approach, followed by more refined risk assessments should the first tier not be satisfied.

The benzene rule preamble established a maximum individual risk (MIR), or the highest estimated risk to an exposed individual in areas that people are believed to occupy, of approximately 1 in 10,000 as the ordinary upper range of acceptability. Since Section 112(f)(2) requires standards to be established using an ample margin of safety, the report also draws on the benzene NESHAPs preamble:

"EPA strives to provide protection to the greatest number of persons possible to an individual lifetime risk level no higher than approximately 1 in 1 million. In the ample margin decision, the Agency again considers all of the health risk and other health information considered in the first step. Beyond that information, additional factors relating to the appropriate level of control will also be considered, including costs and economic impacts of controls, technological feasibility, uncertainties, and any other relevant factors."

The CTWG performed a variety of conservative screening risk analyses to determine how the generic source category would compare with the draft goals of the Section 112(f) Residual Risk Report. The CTWG used the South Coast Air Quality Management District's (SCAQMD) conservative Rule 1401 screening risk assessment protocol for every compound contained in EPA's Emission Inventory for combustion turbines (contained in 70 test runs). The EPA unit risk factor for formaldehyde was used since it was higher than the SCAQMD factor. In most other cases, the SCAQMD unit risk factors were used since they are generally higher than EPA's. Only three facilities fell out over 100 in a million from this analysis. The SCAQMD screening model is very conservative since it uses the highly unrealistic assumption that the turbine exhausts at ambient temperature and, therefore, the plume concentration is essentially linear with distance from the stack. The CTWG ran the three high cases using EPA's screening model (Screen3) that allows assumptions for stack temperature and velocity to be input. The analysis showed that all three cases fell below the draft Section 112(f) benzene guidance. The CTWG notes that even Screen3 uses the worst case meteorological conditions and expects that when further refinements are made using more sophisticated techniques, e.g., ICST with full inputs, that MICR impacts could be reduced by an order of magnitude. This full report, not an attachment to this paper because of its volume, is entitled "Health Risk Analysis of the ICCR Combustion Turbine Emission Database" and can be obtained by contacting Mr. Sims Roy of EPA.

Independently, a conservative screening risk assessment (using the California Air Pollution Control Officers Association [CAPCOA]) performed by Carnot (GRI Report GRI-95/0200, Final Report-Gas Fired Boiler and Turbine Air Toxics Summary Report, August 1996) has demonstrated that there is less than 10^{-6} risk for combustion turbines firing natural gas. See also GRI Report GRI-95/0201, April 1995, Topical Report, Gas PISCES Project Screening Health Risk Assessment, Table 5-1 (Attachments C and D to this paper).

8. Effect of Add-on Exhaust Controls on Efficiency

Several catalyst technologies have been considered by the CTWG for possible control of organic HAPs from combustion turbines. Such technologies impose a thermal efficiency penalty of about 0.175% per inch of H_2O of exhaust back pressure.(1) Typical CO oxidation catalysts have pressure losses around 1 - 1.5 inches of water (when new and clean)(2) and this results in a loss of system thermal efficiency of 0.175 - 0.265%. Pressure losses and the resulting thermal efficiency penalty can be expected to be higher for retrofits in space constrained applications.

The concentration of organic HAPs into the oxidation catalyst will also be an important factor in the amount of pressure loss. The pressure loss through a catalyst in the exhaust system is dependent on the flow area. An open matrix with low surface area will have a smaller loss than a high-density matrix with higher surface area. The catalytic reaction only occurs at the surface of the catalyst and hence to lower an already low HAP value requires a very high density of cells with very high surface area. Therefore, pressure losses for a HAPs oxidation catalyst may be much higher than losses for the typical CO oxidation catalyst discussed above. The resulting thermal efficiency loss should be considered when assessing the cost effectiveness of above the floor alternatives for existing and new turbines.

9. Utility Deregulation and LAER/BACT Developments

Combustion turbines are continuously being forced to meet stricter and stricter criteria emissions standards causing them to be among the cleanest devices under the ICCR's jurisdiction. In previous presentations delivered by the CTWG, concerns were raised that turbines needed closer scrutiny as a result of utility deregulation and the possibility that independent power producers/cogenerators would significantly increase in number and that at least some of these could be located in densely populated areas. The CTWG has carefully considered these concerns. The CTWG believes that there would be a net overall environmental benefit if new facilities and re-powered facilities solely used gas fueled combustion turbines, a benefit that would not be as clear if other forms of fossil fuel were used. Part of this belief stems from the recent LAER activity in Southern California that imposes extremely low pollutant emissions requirements on major sources. Following suit from EPA letters described later in this section, the South Coast Air Quality Management District BACT* Guidelines require, as of June 12, 1998, a one hour average 2.5 ppm NOx standard coupled with a 10 ppm CO standard. This extremely low, not to be exceeded level, would be imposed on <u>all</u> major sources as a result of major source NSR; the CTWG believes that most new independent power producer projects across the country would be major sources. As indicated in the technology seminar sponsored earlier in the ICCR process by the combustion turbine workgroup, low CO, while not an indicator of specific HAPs, is a general overall indicator of good combustion.

Gas turbines have become the electric generation source of choice in the 1990s. With electricity sector deregulation already in place in a few states and likely to come nationally in a few years, that trend is expected to increase. As a result, gas turbines as a class should be considered as a potential major source of emissions of criteria pollutants and should be examined as a possible major source of HAPs. Fortunately, the emissions of pollutants from gas turbines are among the lowest of all combustion sources and the trend is toward even lower levels of criteria emissions through the use of new, improved combustion systems and emission control technologies.

The maximum CO level at which a permit will be granted in CO nonattainment areas is generally 10 ppm. This level is achievable at base load without add-on controls in most modern, heavy duty turbines with diffusion combustors, with some lean-premix combustors and also through the use of oxidation catalysts to control the emissions of CO from combustion turbines that cannot achieve such low levels of CO directly. Since CO is a measure of the completeness of the combustion process as stated earlier, combustors capable of achieving 10 ppm CO or less without add-on controls would also emit very low levels of organic HAPs. Low levels of CO should be indicative of low levels of products of incomplete combustion. While CO is usually not an issue with combustion turbines sited in CO attainment areas and the use of CO oxidizing catalysts is very rare in such cases, except perhaps in California, the low levels of CO achievable without add-on controls still apply. Furthermore, it is not clear that ordinary CO oxidizing catalysts will remove any significant fraction of organic HAPs without correspondingly significant increases in cost and pressure drop as discussed in Section 8 and the CTWG closure paper on cost effectiveness with add-on controls.

Some dramatic advances have been made during the past few years in CO and NOx emission control. The Environmental Protection Agency, Region IX office in San Francisco, issued a letter in July, 1997 declaring that 3.5 ppm NOx (corrected to 15% O_2) on a 3-hour rolling average had been achieved in practice on gas fired combustion turbines using the Goal Line Technologies SCONOX™ catalyst technology. In March 1998, a follow-up letter was issued stating that 2.0 ppm (corrected to 15% O_2) on a three-hour average had been demonstrated in practice using SCONOX and, therefore, would be considered as LAER. This oxidation catalyst reduces NOx without the use of ammonia and also reduces CO emissions. However, SCONOX has only been used to control emissions from a single LM2500 combustion turbine in a cogeneration mode and, as a result, scale-up and scale-down questions have been raised by the regulated community about its reliability and emission control performance for other size combustion turbines. In addition, the cost of SCONOX is significantly greater than that of SCR.

However, SCONOX was only one of several important advances in emission control in the past few years. Most gas turbine manufacturers have developed lean-premix combustors that have achieved low NOx and CO emissions (both 25 ppm or less) without add-on controls (e.g., GE has developed advanced,

* BACT = LAER in the South Coast AQMD.

lean-premix combustion systems for its heavy duty combustion turbines that have achieved less than 9 ppm NOx in practice with correspondingly low CO. These advanced combustion systems are currently available for frame 6B - 36 MW, 7EA - 86MW and 7FA -170MW machines and units in these sizes are operating at 9 ppm NOx with no add-on emission control systems). In addition, there has been an industry wide advance in the thermal efficiency of simple cycle and combined cycle systems during the past 5 years that translates into less fuel burned per kw of output and less pollutant emissions (e.g., the Rolls Royce Trent has achieved a simple cycle efficiency of 42 percent and the DOE advanced turbine program has resulted in H-technology with 60 percent combined cycle thermal efficiency).

Catalytica, Inc. has developed a catalytic combustion system that has been demonstrated at the same low NOx, CO and HAP levels as SCONOX for E-class firing temperatures (2020F) and below with natural gas fuel. The durability of the Catalytica combustion catalyst must still be demonstrated on large combustion turbines. However, all of these new technologies discussed are on the market or about to be marketed and will result in even lower levels of HAPs and other pollutants than existing systems that are already low.

10. Oxidation Catalyst Cost Effectiveness Study for Turbine HAP

The CTWG has conducted a detailed analysis to estimate the base case cost-effectiveness of installing oxidation catalysts on combustion turbines. The results of this analysis demonstrates that the costs to install oxidation catalysts compared to the total HAP emissions reduction is extremely high for gas-fired combustion turbines. Full details are included in the cost effectiveness analysis of add-on catalytic controls also prepared by the CTWG for closure at the September ICCR meeting.

Attachment A
Gaseous Fuels and Natural Gas Equivalency

The ICCR emissions database contains emissions data on 42 turbines firing natural gas, one firing refinery gas and one firing field gas. The emissions data for the refinery gas and the field gas fueled turbine were reviewed to see if the emissions characteristics were equivalent to those from the natural gas fueled turbines. Other gases represented in the database are landfill gas and digester gas, but these are not included in this analysis.

Since not all HAPs compounds were measured in each source test, a rigorous review of equivalency could not be made for each HAP. However, organic HAP data was available for comparison between refinery gas and natural gas for emissions of PAHs and naphthalene and a comparison between field gas and natural gas for emissions of formaldehyde and benzene. The refinery gas fired turbine and the field gas fired turbine were of comparable size and firing temperatures to the natural gas fired turbines in the database. Results are shown in Table A below.

TABLE A

HAP	Natural Gas	Refinery Gas	Field Gas
PAH, #/MMBtu	1.79×10^{-4}*	3.08×10^{-5}	
PAH, TPY		0.138	
Naphthalene, #/MMBtu	1.49×10^{-4}**	2.45×10^{-5}	
Naphthalene, TPY		0.113	
Formaldehyde, #/MMBtu	5.4×10^{-4}	1.64×10^{-4}	
Formaldehyde, TPY			0.085
Benzene, #/MMBtu	2.3×10^{-5}xx		1.0×10^{-5}x
Benzene, TPY			0.0088x

*average for 6 CTs x No benzene detected. - value in the table is based on the detection limit
**average for 7 CTs xx average for 15 CTs
+average for 20 CTs

PAH emissions from the refinery gas fueled combustion turbine were compared with average PAH emissions for 6 natural gas fueled turbines. For this same refinery gas fueled turbine, naphthalene emissions were compared with average naphthalene emissions for 7 natural gas fueled turbines. Based on this limited data it can be seen that refinery gas does indeed have emission characteristics that are of the same order of magnitude as natural gas and the total emissions per year for these two compounds are very low from the refinery gas fueled turbine.

The formaldehyde emissions from the field gas fueled combustion turbine were compared with average formaldehyde emissions for 20 natural gas fired turbines (5.4×10^{-4} lb/MMBtu). For the same field gas fueled turbine, the benzene emissions were not actually detected, and for this case the emissions were conservatively based on the detection limit. This is compared with average benzene emissions for 15 natural gas fueled turbines. Based on these limited data it can be seen that field gas also has emissions characteristics that are of the same order of magnitude as natural gas. The field gas fueled turbine also had very low HAPs emissions per year for these two compounds (i.e., formaldehyde and benzene).

The data available for evaluation of organic emissions from combustion turbines is limited to that reviewed above. The CTWG believes there is substantial additional evidence to corroborate the equivalency between these fuels and natural gas. An extensive study entitled "The Origin and Fate of Toxic Combustion Byproducts in Refinery Heaters: Research to Enable Efficient Compliance with the Clean Air Act" (also known as the PERF report) was completed in 1997 and presented to the ICCR. The results of this study, while directed to external combustion sources fueled by natural gas and process gas, provide valuable insight into the nature of combustors utilizing these fuels.

One of the major findings of the study was "No significant difference in air toxic emissions was revealed between burning natural gas and process gas". A full range of organic emissions were considered in the study including heavy VOCs, light VOCs, aldehydes, PAHs, and phenol. Gas compositions were altered for various tests to simulate a broad spectrum of potential hydrocarbon gases that might be found in various processes. In addition to these compositional variations, a broad range of operating conditions was also represented in the study.

The operational conditions for these studies represent typical burner operating conditions in refinery heaters and boilers. But extreme cases were also simulated that represented various burner control failures. The burner outlet temperature was held at 1600F and nominally operated at 25% excess air. To represent various failure modes, extremes in air supply ranged from 50% of the stoichiometric requirement to a high value of 450% of stoichiometry. It was only the extreme sub-stoichiometric conditions that produced significantly high organic emissions and these conditions would never be found in practical applications because of the inherent dangers from operation with combustibles in the firebox.

By comparison, combustion turbines operate at much higher pressures and inlet temperatures albeit lower detention times than these typical external combustion devices. Typical turbines operate at over 10 atmospheres to as high as 30 atmospheres and inlet air temperatures of over 500 degrees F. Combustion is generally staged with the primary combustion zone operating at slightly above stoichiometric air supply for diffusion flame combustors to around 200 % stoichiometric ratio for lean premix combustors. In both diffusion flame and lean-premix combustors, additional air is added downstream of the primary zone for cooling hot combustion gases and for cooling components. This is necessary because of material limitations on downstream turbine blading. After this addition of cooling air, the exit temperatures from the combustors typically range from 1700F to 2400F for various models of turbines in current production. In direct response to the quest for higher efficiency these temperatures are expected to go up as materials technology is improved in the future. In fact, the next generation of gas turbines (“H” technology), already started in production, has a turbine inlet temperature of 2600F.

As noted above, the stoichiometric ratios for typical combustion turbines are within the range of those tested in the PERF study of external combustion devices. The main differences then in operating conditions of a combustor in a turbine and an external burner is that the turbine will operate at higher pressures, have higher inlet air temperatures and operate at higher exit temperatures and lower detention times than the external burner. The net effect of all of these conditions is known to enhance combustion efficiency and should result in lower emissions of unburned hydrocarbons. Therefore, the results of the PERF study, which show that natural gas and process gases are equivalent in their propensity to form organic emissions and that the levels of these emissions are very low for refinery heaters and boilers, can be extended to also indicate that similar conclusions could be drawn for combustion turbines.

Attachment B
Range of HAP Emission Factors [Average, (Min-Max)]
for Natural Gas-Fired Combustion Turbines in Section AP-42

HAP	# Tests	Average Emission Factor (lb/MMBtu)	Range (Min - Max)
Acetaldehyde	7	9.12E-05	(1.10E-05 - 3.50E-04)
Acrolein	2	5.49E-06	(4.90E-06 - 6.08E-06)
Benzene	11	1.03E-05	(1.34E-06 - 3.91E-05)
Ethylbenzene	1	4.10E-05	---
Formaldehyde	22	7.13E-04	(2.21E-06 - 5.61E-03)
Naphthalene	3	1.46E-06	(5.11E-07 - 3.31E-06)
PAH	4	2.23E-06	(1.44E-07 - 7.32E-06)
Toluene	7	1.42E-04	(1.05E-05 - 7.60E-04)
Xylene	5	4.59E-05	(1.19E-05 - 1.20E-04)

Attachment C

TABLE 4-1
SUMMARY OF CONSERVATIVE SCREENING HEALTH RISK ASSESSMENT RESULTS FOR ONE EXAMPLE UTILITY BOILER FOR EACH FUEL TYPE AND TWO EXAMPLE UTILITY GAS TURBINES

	Natural Gas-Fired Boiler	Oil-Fired Boiler	Coal-Fired Boiler	Natural Gas-Fired Turbine 1 No NO_x Control	Natural Turb Water I
Cancer Risk	0.42×10^{-6} (Cr)	14.3×10^{-6} (Cr)	20.4×10^{-6} (Cr)	0.09×10^{-6} (Cr)	0.10 x 1(
Acute HI*	0.0004 (Ni)	0.0942 (Ni)	0.0323 (Se)	0.0001 (Ni)	0.00(
Chronic HI*	0.0022 (P)	0.0834 (P)	0.0775 (P)	0.0010 (P)	0.00

( ) Parenthesis denotes toxic substance which is the primary contributor to risk or Hazard Index (HI). Abbreviations are as follo hexavalent chromium, Ni = nickel, P = phosphorus, and Se = selenium.

* Values of less than one (1) are below the significance threshold, and are not considered to represent a risk.

Source: GRI-95/0200, Final Report, Gas-Fired Boiler and Turbine Air Toxics Summary Report, August 1996

Attachment D

TABLE 5-1
SUMMARY OF HRA RESULTS

	Natural Gas-Fired Boiler	Oil-Fired Boiler	Coal-Fired Boiler	Natural Gas-Fired Turbine 1 No NO_x Control	Natural Gas-Fired Turbine 2 Water Injection	Coal-Fired Boiler
Cancer Risk	4.188×10^{-7} (Cr)	1.434×10^{-5} (Cr)	2.045×10^{-5} (Cr)	9.295×10^{-8} (Cr)	1.033×10^{-7} (Cr)	1.624×10^{-5} (Cr)
Acute HI	0.0004 (Ni)	0.0942 (Ni)	0.0323 (Se)	0.0001 (Ni)	0.0001 (Ni)	0.0256 (Se)
Chronic HI	0.0022 (P)	0.0834 (P)	0.0775 (P)	0.0010 (P)	0.0009 (P)	0.0615 (P)
Stack Gas Temp (°F)	271	271	271	842	1,098	371
Stack Height (m)	76	76	76	17	40	76
CHI/Q	0.8062	0.8490	0.8440	0.3688	0.2391	0.6700
Distance to Maximum Impact (m) (MEI)	1134	1117	1119	1328	1494	1200

( ) Parenthesis denotes toxic substance which are primary contributors to risk or hazard index (HI). Abbreviations are as follows: Cr = hexavalent chromium, Ni = nickel, P = phosphorus, and Se = selenium.

CHI/Q Site specific dispersion factor.

MEI Denotes the maximally exposed individual, a hypothetical (not actual) receptor assumed to reside at the point of maximum impact for 70 years.

Source: GRI-95/0201, Topical Report, Gas PICES Project Screening Health Risk Assessment, April 1995

REFERENCES FOR SECTION 8

(1) Gas Turbine World 1997 Handbook, Volume 18, Page 120, Waste Heat Recovery Steam curves with unfired HRSGs

(2) ENGELHARD Letter of April 27, 1998 from Fred A. Booth, Phone (410) 569-0297, to S.A. Allen